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Numerical investigation into the buckling behaviour of an advanced bridge bearing using 3D printing method for Thai highway bridges

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ABSTRACT: Steel-reinforced elastomeric bearings also referred to rubber bearings have been widely used for highway bridges in Thailand. Their major functions are not only to accommodate the lateral movement between the superstructure and substructure, but also to carry the weight of the superstructure. Elastomeric bearings are installed under the superstructures of bridges with different types, based on the length of bridge span. Additionally, they can reduce vibration induced by dynamic actions. However, these typical bearings cannot well perform under various loading conditions due to conventional structures in the bearings. Besides, the materials used in the bearings are costly and cannot be durable over time of bridge operation. This is because commonly elastomeric bearings consist of steel plates laminated between rubber layers. Therefore, the complex and porous structures also called metastructures which could be employed in bridge bearings are required in design for obtaining superior mechanical properties. To fabricate advanced bridge bearings with complicated internal structures, it is strongly suggested to use additive manufacturing or well-known as 3D printing throughout processing. The technique of 3D printing is quicker than conventional manufacturing including injection molds and subtractive production. This paper is the world's first to highlight the buckling behaviour of an advanced bridge bearing simulation using an additive manufacturing technology under static loading. The insights will be useful for Thai highway engineers to develop generally elastomeric bearings. On the other hand, further experimental research should be conducted to improve and verify the advanced 3D bearing model in the future for public use.

1 INTRODUCTION

The deformations between the superstructure and the substructure of a common highway bridge in Thailand are facilitated by bridge isolators or called bridge bearings. Their functions are not only to accommodate these deformations, but also to transmit loads from the superstructure to the foundation, according to Sengsri, Marsico & Kaewunruen (2019). The STANDARD DRAWINGS for Thai highway design and construction, dependent on STANDARD DRAWINGS (2015), defines bridge isolators as an engineered device which transfers forces, whilst accommodating displacement. For comprehending deformation in vertical and horizontal direction, which isolators are used for building applications, according to Naeim & Kelly (1999), but for employing them in bridge system they will besides undergo rotational deformations (Lee, 1994, Al-Anany & Tait 2016).

According to studies in (Constantinou et al. 2011, Al-Anany 2016), the vertical stiffness of bridge isolators should be adequate to transfer forces and also to facilitate the lateral and rotational displacements

occurred in the girders. One of the most accelerating deterioration to a bridge is the failure of bridge isolators, based on AASHTO (2012). Thus, under unexpected loading, damage is not allowed to appear in bridge isolators. There are many effects on the selection of an isolator type, including the predicted forces, geometry, maintenance, available materials, deformation requirements, and so on, based on a review in, a review in Caltrans (1994).

Most of the bearing types used in Thai highway bridges are rubber bearings, as well-known as elastomeric bearings, with reinforcement using thin steel plates. Accordingly, the key element of a rubber isolator is the rubber pads, according to Kelly & Constantinidis (2011). However, these pads can be utilised directly without any reinforcement (e.g. plain rubber bearings) or using the reinforcement in them is to obtain an extreme tensile capacity for rising the vertical stiffness of the bearing by controlling buckling of the rubber.

More recently, the development of common bridge isolators has become attractive for bridge engineers to gain superior mechanical properties as advanced bridge bearings. Isolators, which are tradi-

tionally reinforced with steel plates, can optionally employ fibre materials. Reviews in (Al-Anany et al. 2016, Ashkezari et al. 2008, Kang et al. 2003, Kelly 1999, Kelly 2001, Moon et al 2002, Mordini & Strauss 2008, Naghshineh & Akyüz 2014, Naghshineh et al. 2015, Toopchi-Nezhad et al. 2008, Van Engelen 2015), they show numerous investigations on the viability of replacing steel reinforcement with fibre reinforcement.

Currently, metamaterials, also referring to as advanced materials, basically consists of metastructures which function to well perform under various loading conditions, due to their better mechanical properties. For examples of their properties, these metamaterials could provide superior stress and noise mitigation, impact resistance, lightweight, indentation resistance, excellent electric and thermal conductivity, and longer lifecycle over bridge operation (Evans et al. 1991, Saxena 2016).

In terms of metamaterials, they commonly exhibit the behaviours from the combination of structures, not from their properties, for instance, auxetic behaviours. Reviews in (Evans et al. 1991, Saxena 2016), under compressive loading, the materials with positive Poisson's ratio also well-known as PR show a particular behaviour as a swelling perpendicular to the direction of compression loading conditions. On the other hand, the advanced materials (metamaterials) with negative PR express a shrink behaviour in the lateral direction under the same condition. Therefore, these advanced materials with negative PR provide better mechanical properties and performances when compared to typical materials (Kolken & Zadpoor 2017, Robbins et al. 2016). In this paper, we will focus on the development of a meta-functional seismic isolator for a Thai highway bridge by using a complex and porous structure that will be presented in the following section.

2 METHODS

2.1 CAD simulation

More recently, the development of common bridge bearings has been extensively investigated for gaining their better mechanical properties. In this paper, a model was created by using Fusion 360 software. This software is also very suitable to simply print 3D objects' layer by layer. The geometry of the model is based on the STANDARD DRAWINGS for Thai highway design and construction, based on STANDARD DRAWINGS (2015), for example height, length, and width, but the shape is dependent on a user's demand such as fashioned, structural,

and porous model. Figure 1 shows the CAD model of an advanced bridge bearing was designed.



Figure 1. CAD simulation of an advanced bridge bearing.

2.2 Shape optimisation method

In general, shape optimisation is part of study area of optimal control theory. The common issue is to determine the shape, which is optimal for reducing a certain cost functional, whilst meeting given constraints. Nevertheless, in engineering, this method has been widely used for many application purposes. Their benefits are not only to decrease the costs, but also to reduce materials that do not support load pathways or called critical load pathways. Thus, it is important to consider the optimal shapes of engineered objects in design for many applications. Another benefit of using the shape optimisation technique is metamaterials have lightweight and good heat transfer due to their superior shape after optimising. After obtaining the optimal 3D model, the model will be investigated for buckling testing by finite element method (FEM) in the following section.

2.3 Finite element analysis (FEA)

The finite element method was used to investigate the buckling behaviour of the model under static loading condition. It is significant to test how strong the model is under any loading conditions. This means that the structure of the model with removing unloaded materials in the shape optimisation process is strong enough for design in terms of load cases applied. The material properties and geometry of this model are given in Table 1. These properties were selected due to the most use and manufacturing of common bridge bearings for highway bridges in Thailand. A buckling behaviour was performed to evaluate the quality of the finite element (FE) simulation. It is clear that this model acting as an advanced bridge bearing can give agreeable estimation of bridge bearing's buckling behaviour under static loading. However, the result from this model should be compared with the experiment data in the near future for improving the model and public use.

2.4 Additive manufacturing (AM)

Additive manufacturing (AM) is a modern method to fabricate 3D haptic physical objects layer by layer, dependent on the geometry of CAD models, based on EN 15129 (2010). Several 3D printing techniques can manufacture 3D printed polymer composites. Their key features of these techniques are not only to produce composite materials, but also to provide complicated internal structures in the materials as well as fast manufacturing processes (a couple of hours to be completed). Some of these AM methods have their advantages and limits in fabricating composite materials and complex internal structures (Sood et al. 2010). In this paper, the most suitable 3D printing method for our model could be the fused deposition modelling (FDM). This is because it provides eco-friendly objects, effective cost, good strength property, multi-material capability, according to Wang (2017).

Table 1. Engineering properties and dimensions employed in the simulation.

Parameter lists	Value	Unit
Young's modulus	0.002	GPa
Poisson's ratio	0.49	-
Density	0.001	g/mm ³
Length	420	mm
Width	420	mm
Height	200	mm
Surface area	1.847E+06	mm ²
Volume	3.679E+06	mm ³
Mass	4415.392	g
Material	Rubber, Nitrile	-

3 RESULTS

3.1 Critical load paths

Figure 2 shows the critical load pathways in the simulation of an advanced bridge bearing. It is obvious that the optimal model can distribute pressure (0.5 MPa, presented as the blue arrow) to the bottom of model. The most critical load paths are expressed as red colour and the green load paths can be considered to remove or remain to make the model more porous. On the other hand, the removal of material is based on the ability to resist and deform of the model's structure under any loading conditions.

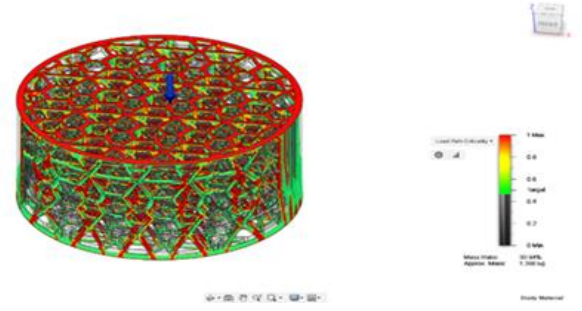


Figure 2. Critical load pathways of optimal model for an advanced bridge bearing under static loading.

3.2 Bulking behaviour

Figure 3 illustrates the buckling behaviour of the modelling for an advanced bridge bearing under static loading condition, using finite element method. The maximum deformation in vertical direction is 69 mm. Obviously, the metastructure in our model could well perform due to its stability, when compared with a typical bridge bearing. It is important to note that this model is still being developed and investigated.



Figure 3. Buckling behaviour of the simulation for an advanced bridge bearing under compressive pressure condition.

4 CONCLUSIONS

Buckling behaviour of bridge bearings in highway bridge system plays a significant role in the improvement of the comprehension into the design and manufacturing of the metamaterial used in these bearings under various compression loading. The buckling behaviour of our model were examined, using the finite element approach with Fusion 360 software to both create the CAD and finite element model. The insights into the buckling behaviour of an advanced bridge bearing will help bridge engineers to develop design guidelines of common bridge bearing to obtain superior mechanical properties. Also, the additive manufacturing is likely to be used for generating these meta-functional bridge bearings with complex structures. Further research

on experiment tests should be conducted in order to improve and verify the simulation for public use.

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